(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 April 2002 (11.04.2002)

PCT

(10) International Publication Number
WO 02/29232 A1

(51) International Patent Classification[7]: F02K 1/38

(21) International Application Number: PCT/US01/30862

(22) International Filing Date: 2 October 2001 (02.10.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/237,314 2 October 2000 (02.10.2000) US

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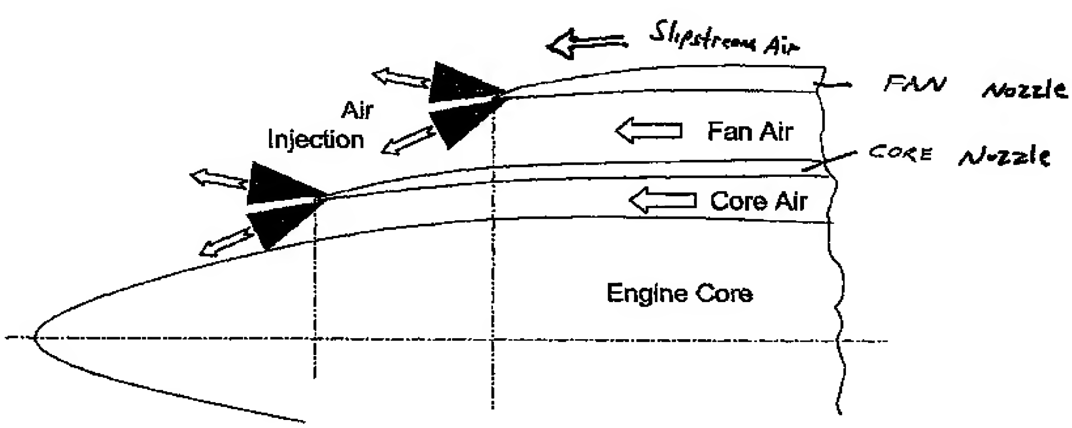
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: APPARATUS, METHOD AND SYSTEM FOR GAS TURBINE ENGINE NOISE REDUCTION



(57) **Abstract:** An apparatus for reducing gas turbine engine noise, such as noise generated by an aircraft gas turbine engine, comprises at least one and preferably a plurality of gas injectors for injecting gas such as high pressure engine bleed air, diverted core air, air obtained from a pressurized storage container or air obtained from a synthetic jet actuator into the area proximate to one or more engine nozzle portions, thereby disrupting the noise-generating gas streams generated by the engine exhaust and the travel of the airplane through the air. The apparatus is particularly useful for reducing engine noise during the takeoff period of aircraft flight.

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APPARATUS, METHOD AND SYSTEM FOR GAS TURBINE ENGINE NOISE REDUCTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus, method and system for reducing the noise generated by gas turbine engines, particularly aircraft gas turbine engines. More particularly, this invention relates to an apparatus in which a separate gas stream such as air is introduced at one or more engine nozzle portions to disrupt the noise-generating gas streams ordinarily generated by the engine exhaust. The method and system of this invention use such an apparatus to reduce gas turbine engine noise, particularly during high noise generating periods such as aircraft takeoff.

2. Background Information

The desirability of reducing noise generated by gas turbine engines is well known to those skilled in the art. More particularly, it is well known that gas turbine engines used in aircraft generate undesirable noise levels, particularly during the takeoff period of the aircraft. Extensive testing on using tabs and chevrons in aircraft gas turbine engine exhaust mixers have shown promise in reducing engine exhaust noise during takeoff. It is believed that such tabs and chevrons break up the large scale, low frequency exhaust flow into smaller, high frequency components. These high frequency components are believed to dissipate quickly in the atmosphere without reaching the ground. However, the performance losses associated with the use of such tabs and chevrons becomes prohibitive for long range aircraft where cruise performance is the driving design parameter. Accordingly, it is desirable to employ a method, apparatus and system for reducing noise in such engines which avoids such detrimental cruise performance losses.

Accordingly, it is one object of this invention to provide an apparatus to reduce gas turbine engine noise, particularly during high noise generating periods such as aircraft takeoff, while minimizing aircraft cruise performance losses. In the apparatus of this invention at least one separate gas stream is introduced proximate to

or at one or more engine nozzle portions to disrupt the noise-generating gas streams ordinarily generated by the engine exhaust. The method and system of this invention use such an apparatus to reduce gas turbine engine noise, particularly during high noise generating periods such as aircraft takeoff, yet avoid or minimize detrimental cruise performance losses. Other objects, features and advantages of the apparatus, method and system of this invention will be apparent from the detailed description herein.

SUMMARY OF THE INVENTION

This invention is directed to an apparatus, method and system for reducing gas turbine engine noise, such as noise generated by an aircraft gas turbine engine particularly during high noise generating periods such as aircraft takeoff, while minimizing aircraft cruise performance losses. More specifically, in the apparatus of this invention a separate gas stream, preferably high pressure air such as engine bleed air, diverted core air or air from a pressurized storage container or a combination thereof is introduced in an area proximate to one or more engine nozzle portions to disrupt the noise-generating gas streams ordinarily generated by the engine exhaust and the travel of the airplane through the air. The gas may be injected using, for example, at least one gas injector which introduces the gas in the desired area. The gas may be as a steady or continuous stream, or may be injected in a pulsing manner in which either all of the injectors pulse simulataneously or the injectors pulse sequentially around the perimeter of the engine nozzle portion or portions. Alternatively, one or more synthetic jet actuators located proximate to at least one trailing edge of at least one engine nozzle portion may be used to introduce the desired gas stream into the desired location. The gas injector or injectors and one or more synthetic jet actuators may also be used in combination to achieve the desired gas injection. The apparatus of this invention comprises at least one, and preferably a plurality of, gas injectors, synthetic jet actuators or combinations thereof for introducing gas into the area proximate to one or more engine nozzle portions. Various configurations and locations for the gas injectors, synthetic jet actuators, or

combinations thereof, as described herein, may be employed to achieve the desired noise reduction.

The method of this invention is a method for reducing noise generated by an aircraft gas turbine engine, the method comprising:

(a) providing an apparatus for reducing noise generated by a gas turbine engine, the apparatus comprising at least one, and preferably a plurality, of gas injectors, synthetic jet actuators or a combination thereof for injecting gas into the area proximate to one or more engine nozzle portions ; and

(b) introducing gas into the apparatus during a takeoff portion of aircraft flight, wherein the gas is injected proximate to one or more engine nozzle portions to disrupt the noise-generating gas streams.

In the system of this invention, noise generated by an aircraft gas turbine engine is reduced using a system comprising:

(a) a source of gas such as air; and

(b) an apparatus for reducing noise generated by a gas turbine engine, the apparatus comprising at least one, and preferably a plurality, of gas injectors or synthetic ject actuators or both for injecting the gas into the area proximate to one or more engine nozzle portions.

In the method and system of this invention, the introduction of gas such as air into the apparatus is preferably halted during the cruise portion of the aircraft flight to avoid or reduce performance losses.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A depicts an aircraft gas turbine engine and shows a preferred location of the apparatus of this invention on the engine.

Figure 1B depicts an embodiment of the apparatus of this invention in which mixing of the noise-generating gas streams is achieved by injecting air directly into the fan and core streams at the engine nozzle exit plane, as shown in further detail in Figure 1F.

Figure 1C depicts a cross-sectional view of the aircraft gas turbine engine core, air flow patterns and theorized gas flow patterns with respect to the apparatus of this invention.

Figure 1D depicts an embodiment of the apparatus of this invention in which the aircraft gas turbine engine exhaust nozzle has crescent- shaped injectors for injecting air on the fan flow side aft of the nozzle exit plane.

Figure 1E depicts an embodiment of the apparatus of this invention in which the aircraft gas turbine engine exhaust nozzle has injectors for ejecting air from under the core cowl of the engine.

Figure 1F depicts an embodiment of the apparatus of this invention in which mixing of the noise-generating gas streams is achieved by injecting air directly into the fan and core streams at the engine nozzle exit plane.

Figure 1G depicts an embodiment of the apparatus of this invention in which air is supplied to injectors via an air delivery tube and injected between inner and outer scalloped barrels of an aircraft gas turbine engine exhaust nozzle.

Figure 1H depicts an embodiment of the apparatus of this invention as depicted in Figure 1G in which the delivery tube is located proximate or just forward of the exhaust plane.

Figure 2 depicts the overall configuration of the experimental apparatus described in Example 1 herein.

Figure 3 depicts the control valve arrangement used in the experimental apparatus described in Example 1 herein.

Figure 4 depicts the transition duct arrangement used in the experimental apparatus described in Example 1 herein.

Figure 5a depicts a wedge splitter plate mixer used in the experimental apparatus described in Example 1 herein.

Figure 5b depicts a sawtoothed shaped tab mixer used in the experimental apparatus described in Example 1 herein.

Figure 6 depicts flow conditions obtained using the sawtoothed shaped tab mixer in the experimental apparatus described in Example 1 herein.

Figures 7 and 8 depict flow conditions obtained using the air injection mixer in the experimental apparatus described in Example 1 herein.

Figure 9 depicts representative flow patterns for various mixer designs which may be used in the apparatus of this invention.

Figure 10 depicts a representative flow pattern for an injection/wedge combination mixer design which may be used in the apparatus of this invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention is directed to an apparatus, method and system for reducing gas turbine engine noise, particularly during high noise generating periods such as aircraft takeoff, while minimizing aircraft cruise performance losses. More specifically, in the apparatus of this invention at least one separate gas stream such as an air stream is introduced proximate to one or more engine nozzle portions such as the fan nozzle, core nozzle or both to disrupt the noise-generating gas streams ordinarily generated by the engine exhaust. The purpose of the introduction of the separate gas stream or streams is to create the same effect as a mechanical tab mixer, but to avoid or minimize aircraft cruise performance losses typically associated with such mechanical mixers. This introduction of gas such as air has the advantage of disturbing the flow during takeoff (with some possible attendant performance loss due to, for example, engine bleed air required for injection). However, during cruise, the air supply would preferably be turned off so there would be no loss in performance such as bleed air penalty. The introduced gas may be air obtained for example from a high pressure air source such as engine bleed air, diverted core air or air from a pressurized storage container, and injected into the desired location via gas injectors. Alternatively, one or more synthetic jet actuators (described further herein) located proximate to at least one trailing edge of at least one engine nozzle portion may be used to introduce the desired gas stream into the desired location. In the method and system of this invention, the apparatus of this invention is installed on a gas turbine engine such as an aircraft gas turbine engine, and the gas injector or injectors, if employed, may be supplied with a separate source of gas such as engine bleed air, diverted core air or air from a pressurized storage container via duct work, a plenum or the like during takeoff to reduce engine noise associated with the engine's exhaust. The apparatus is responsively interconnected to a control system which enables the

separate gas source supply to be turned off during the cruise or other portions of the aircraft's flight.

An overall illustration of the invention is set forth in Figures 1A-1C. Figure 1A depicts an aircraft gas turbine engine and shows the location of the apparatus of this invention on the engine. Figure 1B depicts one embodiment of the apparatus of this invention, discussed further herein with respect to Figure 1F. Figure 1C depicts a cross-sectional view of the aircraft gas turbine engine core, air flow patterns and theorized gas flow patterns with respect to the apparatus of this invention. More, particularly, in Figure 1C, embodiments of this invention are depicted in which air such as engine bleed air, diverted core air, air from a pressurized storage container or air obtained from a synthetic jet actuator may be injected either proximate to the core nozzle, injected proximate to the fan nozzle, or both. If the air is injected proximate to the core nozzle, the injected air is intermixed with the core air as well as fan air, as shown. If the air is injected proximate to the fan nozzle, the injected air is intermixed with the fan air as well as slipstream air, as shown. Air injection has a greater effect on noise reduction if injected proximate to the core nozzle due to the high differential air velocities at the core air-fan air interface. Air injection has a lesser but valuable effect on noise reduction if injected proximate to the fan nozzle due to the lower differential air velocities at the fan air-slipstream air interface.

An illustration of another embodiment of the apparatus of this invention is shown in Figure 1D, which depicts an aircraft gas turbine engine exhaust nozzle having crescent-shaped injectors for injecting air on the fan flow side aft of the nozzle exit plane. Similar injectors may optionally also be added to the core side. The injectors receive the air from piping, ducting, a plenum or asynthetic jet actuator (not shown).

An illustration of another embodiment of the apparatus of this invention is shown in Figure 1E, which depicts an aircraft gas turbine engine exhaust nozzle having injectors for injecting air from under the core cowl of the engine. The nozzle may optionally have flutes to direct and control the air to the core exhaust plane, as shown. The injectors receive the air from piping, ducting, a plenum or a synthetic jet actuator (not shown).

An illustration of another embodiment of the apparatus of this invention is shown in Figure 1F, which depicts the aircraft gas turbine engine exhaust nozzle of Figure 1B in greater detail. In this embodiment, mixing of the gas streams is achieved by injecting air directly into the fan and core streams at the nozzle exit plane. The shape of the holes used for injection may range from slotted as shown to round, or a combination thereof. The angle of penetration may be varied from streamwise with the flow to streamwise against the flow, or any intermediate position therebetween. The injectors receive the air from piping, ducting, a plenum or a synthetic jet actuator (not shown).

An illustration of another embodiment of the apparatus of this invention is shown in Figures 1G and 1H. In this embodiment, air is injected between the inner and outer barrels of an aircraft gas turbine engine exhaust nozzle from an air delivery tube which runs around the entire 360 degree circumference of the exhaust nozzle, as shown in greater detail in Figure 1H. As is also depicted in Figure 1G, in a preferred embodiment the inner and outer barrels may be scalloped to provide a local shroud to either direct the air into the fan stream or the core flow. As depicted in Figure 1H, in a preferred embodiment the delivery tube is positioned proximate or just forward of the exhaust plane. The air delivery tube is fed air from piping, ducting, a plenum or a synthetic jet actuator (not shown). In the embodiment of Figure 1H, the delivery tube has slot-shaped injector orifices, although circular-shaped orifices may also be used, or combinations of slot-shaped and circular-shaped orifices. Other orifice shapes may also be used, either alone or in combination with the slot-shaped and circular-shaped orifices.

As discussed above, in one embodiment of this invention one or more synthetic jet actuators may be used to provide the air injected into the desired location. As is well known to those skilled in the art, a synthetic jet actuator operates by intaking a gas such as air from a given location and injecting the gas proximate to the same location with a forced velocity sufficient to induce a vortex stream into the desired flow region. In this invention, one or more synthetic jet actuators may be employed, for example, to intake air from the region proximate to the nozzle region of an aircraft engine (as depicted, for example, in Fig. 1C) and inject the air with a forced velocity sufficient to induce a vortex stream into the desired flow region (e.g.

the core air flow region, the fan air flow region, or a combination thereof, as depicted in Fig. 1C). The synthetic jet actuator, if employed, does not cause any additional air or gas mass flow rate to be added to the engine nozzle flow. In this invention, one or more synthetic jet actuators may be employed without additional air sources to achieve the desired air injection, or one or more synthetic jet actuators may be used in combination with one or more air or gas sources such as engine bleed air, diverted core air, a separate pressurized air storage container and the like to achieve the desired air injection at the desired location. Without wishing to be bound by any one theory, it is believed that use of one or more synthetic jet actuators in this invention is advantageous because performance losses such as bleed air losses will not be incurred or will be minimized. Synthetic jet actuators are well known to those skilled in the art, and synthetic jet actuators which may be employed in this invention are described, for example, in U.S. Patent Nos. 5,758,823; 5,957,413; and 6,056,204 as well as Lachowicz et al. "Physical Analysis and Scaling of a Jet and Vortex Actuator," in *3rd Joint ASME/JSME Fluids Engineering Conference*, San Francisco, California (July 18-22, 1999) (FEDSM99-6921) (referred to herein as Lachowicz et al.), all of which are incorporated herein by reference in their entirety.

More particularly, in one embodiment of this invention the synthetic jet actuator employed is as described in U.S. Pat. No 5,040,560, in which the jet actuator employs one or more piezoelectric actuators to obtain controlled disturbances within the primary flow stream (e.g. the core air flow, engine air flow or combination thereof as depicted in Fig. 1C of this application.

In another embodiment of this invention, the synthetic jet actuator employed is as described in U.S. Pat. No. 5,758,823, in which the actuator comprises a housing defining an internal chamber. An orifice is present in a wall of the housing, and a mechanism is included in or proximate to the housing to periodically change the volume within the internal chamber so that a series of fluid vortices are generated and projected externally from the housing orifice. The volume changing mechanism may be, for example, a piston positioned in the jet housing so that fluid is moved in and out of the orifice during reciprocation of the piston. A flexible diaphragm may be used as a wall of the housing to act in conjunction with the volume changing mechanism. A control system is used to create time harmonic motion of the

diaphragm, such that as the diaphragm moves into the chamber, thereby decreasing the chamber volume, fluid is ejected from the chamber through the orifice. As the fluid passes through the orifice, the flow separates at the sharp edges of the orifice and creates vortex sheets which roll up into vortices. These vortices move away from the edges of the orifice under their own self-induced velocity, thereby synthesizing a fluid jet.

In another embodiment of this invention, the synthetic jet actuator employed is as described in the first preferred embodiment of U.S. Pat. No 5,957,413, in which the actuator is as described in U.S. Patent No. 5,758,823, and the flexible diaphragm employed therein may be actuated by a piezoelectric actuator or other appropriate means. In this embodiment, the actuator may also be further modified to include a device or mechanism for withdrawing fluid into the chamber and for forcing fluid out of the chamber through the orifice. at least one louver is attached to the housing and is aligned with an opening formed in the housing. The louver is a one-way valve and only permits fluid flow in one direction. Accordingly, the louver permits fluid flow either into the chamber through the opening or out of the chamber through the opening. The louver may be a passive louver or an active louver, such as a louver whose position is at least partially controlled by a piezoelectric material or other suitable means. In another embodiment of this invention, the synthetic jet actuator employed is as described in the second preferred embodiment of U.S. Pat. No 5,957,413, in which the actuator is embedded in a body and operates through the outer surface of the body. More particularly, in this embodiment two concentric tubular sections or pipes are embedded in a solid body, normal to the outside surface. The outer of the two pipes is preferably connected to a source of fluid with a means for pulsing a fluid out of this pipe. The innermost of the two pipes is connected to an appropriate means for pulling fluid down this pipe from the ambient fluid above the planar surface, such as a vacuum or fluid pump. The innermost pipe is situated such that its exit plane is slightly below the planar surface; thus in operation the innermost pipe will constantly pull fluid down its length from the ambient fluid above the falt, planar surface, while the outer pipe is caused to pulse fluid into the ambient environment above the planar surface, thereby causing a fluid jet to form above the constant suction synthetic jet actuator.

In another embodiment of this invention, the synthetic jet actuator employed is as described in U.S. Pat. No 6,056,204, in which the synthetic jet actuators of U.S. Patent Nos. 5,758,823 and 5,957,413 are aligned perpindicular to the primary fluid flow (e.g. the core air flow, fan air flow or combination thereof as depicted In Fig. 1C of this application). In another embodiment of this invention, a synthetic control jet is attached to the top housing of a primary jet as described in U.S. Pat. No. 6,056,204 such that the direction of flow of the control jet is parallel to the direction of the primary jet flow. If the two jets are operated at the same time, the synthetic control jet actuator will "vector" the primary jet flow.

In yet another embodiment of this invention, the synthetic jet actuator employed is as described in Lachowicz et al., in which the synthetic jet actuator consists of a cavity and rigid plate which serves as the actuation surface. The plate is oscillated vertically such that the plate's motion is displaced uniformly around its length and width. The plate thus acts as a piston, pumping air out of the cavity on the downstroke and sucking air into the cavity on the upstroke. The plate is placed asymmetrically over the cavity opening, forming narrow and wide slots as depicted in Figure 1 of Lachowicz et al.

Particular embodiments of the invention are described in the following example, which is not meant to limit the invention in any way.

Example 1

A test apparatus was built to examine the effect of different tab designs. The apparatus consisted of two transition ducts and three different mixer designs. The ducts were attached to a preexisting airflow facility. The overall test setup is shown in Figure 2.

Control Valve Arrangement

The airflow facility consisted of a series of pipes that attached to 4 large reservoir tanks. The pipes supply to various test facilities. For the described test, an 8" stub-off was used for testing. Air from the 8" stub-off flowed through two diverging branches, each of which was 5" in diameter. Air for the air tab nozzle was supplied from a 1" stub-off from the main supply line. The arrangement is shown in greater detail in Figure 3.

Transition Ducts

Transition ducts were mounted at the end of the 5" lines. The ducts were constructed to represent fan and core stream mass flows. Because each 5" line was from the same supply line, the test configuration only allowed for cold flow testing. The transition ducts consisted of a fiberglass section and a steel section. The fiberglass section transitioned from 5" round to a rectangular cross section (3.25" x 6" for the core flow and 4" x 6" for the fan flow). The steel section turned and reduced the rectangular cross section to the final exit area (2" x 6" for the core flow and 3" x 6" for the fan flow). The transition ducts are shown in Figure 4.

Mixer Configurations

Three different mixer designs were attached at the end of the transition sections. The first mixer design was a simple wedge splitter plate to represent a typical exhaust nozzle (Figure 5a). The second was a sawtooth shaped tab mixer (Figure 5b). All configurations were mechanically fastened to the transition ducts. The air tab mixer was supplied from both ends from the 1" stub-off shown in Figure 3.

Test Results

Each 5" line was equipped with an orifice plate for mass flow measurements. The largest orifice plates that could be located by the test labs were 3", which significantly reduced the available flow. An alternative approach selected was to remove the orifice plates to allow the maximum amount of flow through the test apparatus. A total pressure probe was installed in the center of the exit plane of each transition duct (assuming an even flow profile at the exit plane). Air temperature was recorded from instrumentation at the orifice plate area of the test setup. Mass flow could then be computed post-test from:

$$\dot{m} = \frac{p_t}{\sqrt{RT_t}} A\sqrt{\gamma} M\left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma+1}{2(1-\gamma)}} \text{ and } \frac{p_t}{p} = \left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}$$

where $\dot{m}$ is the mass flow rate, A is the cross section area, M is the flow Mach number, p_t is the total pressure, p is the static pressure (assumed to be ambient), γ is the gas constant or ratio of specific heats, and T_t is the total temperature.

Total mass flow available from the airflow facility was approximately 11 $1b_m$/s. Core total pressure were varied from 0.5 psig (1.6 $1b_m$/s) to 2.5 psig (3.5 $1b_m$/s). Fan total pressures were varied from 0.5 psig (2.3 $1b_m$/s) to 5.3 psig (7.5 $1b_m$/s). Air injection total pressures were varied from 0.0 psig (0 $1b_m$/s) to 5.0 psig (0.22 $1b_m$/s).

Wedge Mixer

The flow exiting over the wedge mixer was very smooth. The tufts of the flow visualization wand oscillated only a few degrees to either side of the centerline. No useful photos are available.

Saw Tooth Tab Mixer

The saw tooth tab mixer significantly disturbed the flow. The shear layer behind the mixer was wider and much more turbulent. Tufts from the flow visualization want showed oscillations of about 15 degrees to either side of the centerline. Vertical oscillations (along the length of the splitter) were small (Figure 6).

Air Injection Mixer

The flow exiting over the air injection mixer with the air injection off was very smooth. Immediately behind the injector, the flow was somewhat turbulent. A few injector diameters downstream of the injector, however, the flow was similar to the wedge mixer.

With the injection system turned on, the flow was noticeably disturbed. At the lowest set point for injection (about 0.09 $1b_m$/s), the tufts of the flow visualization wand oscillated about 15 degrees to either side of the centerline (the same as the saw tooth mixer). At higher injection flows, the oscillations increased to about 45 degrees to either side of the centerline. Side displacements of the wand were also noticeably larger with the flow turned on. (See Figures 7 and 8).

Comparison of Mixers

Figure 9 provides a comparison of flow visualization of the different mixers.

Conclusions

Air requirements (e.g. bleed air requirements) may be a concern for implementation of this system. Air flows used in this example were 4%-7% of the core flow. As a comparison, typical nacelle anti-icing systems use slightly less than 1% bleed of the core flow at takeoff power. Without wishing to be bound by any one theory it is believed that these air flows should scale proportionally to a full scale application. It also should be noted that, unlike an anti-icing system, bleed air flow is exhausted from the back of the engine so some thrust will be obtained, albeit not in the most desired manner.

Due to limitations of the airflow facility, take-off duct pressures (about 27 psia) were not obtainable. The highest duct pressures obtainable were approximately 20 psia. Higher takeoff pressures would require more flow in both the ducts and the injection system.

This test was designed to demonstrate the viability of the concept of using air injection to disturb the fan and core flows and hopefully break up large scale, low frequency structures in the flow. The test apparatus was not optimized for production use. Possible additional features and /or improvements of the invention in terms of cruise performance include placing a wedge fairing behind the injector bar to keep the flow moving smoothly behind the mixer when the air supply is off. An embodiment which is a combination injection/wedge mixer is depicted in Figure 10.

In addition, in the test apparatus the injector supply tube diameter was limited to 0.5" for ease of manufacturing this single piece of test hardware. The actual air delivery system for a production nozzle would probably be different than the test setup. One option is to implement the production nozzle as a spray bar type system. In such a scenario, the diameter of the spray bar will need to be chosen so that the cross section area is much larger than the total injector exit area to ensure uniform flow through the injectors. If the nozzle could be built as a pressure reservoir, then the spray bar diameter is not an issue.

To fully examine additional benefits and uses of the invention, it would be desirable to conduct additional testing in a facility and/or full scale engine tests with acceptable acoustic and flow measurement capabilities.

While preferred embodiments of the present invention have been illustrated and described, it should be understood that variations could be made therein without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the invention is not to be limited to the specific embodiments illustrated and described. Rather the true scope and spirit of the invention are to be determined by reference to the following claims.

The invention claimed is:

1. An apparatus for reducing noise generated by a gas turbine engine, the apparatus comprising at least one gas injector for injecting gas into the area proximate to one or more engine nozzle portions.

2. The apparatus of claim 1, in which the injector is crescent-shaped.

3. The apparatus of claim 1, in which the injector is located on the fan flow side of the nozzle exit plane.

4. The apparatus of claim 1, in which the injector is located on the core side of the engine.

5. The apparatus of claim 1, in which the nozzle comprises flutes for directing the gas.

6. The apparatus of claim 1, in which the engine has a core cowl, and the gas is injected under the cowl.

7. The apparatus of claim 1, in which the engine has a fan nozzle and a core nozzle, and the injectors are positioned to inject gas directly into the fan and core gas streams in the nozzle exit plane.

8. The apparatus of claim 1, in which the injector has a plurality of gas exit ports having a shape selected from the group consisting of slotted, circular or combinations thereof.

9. The apparatus of claim 1, in which the injector is positioned to inject gas in a direction ranging from streamwise with the flow of gases from the engine to streamwise against the flow of gases from the engine.

10. The apparatus of claim 1, in which the injector is located between the inner and outer barrels of the exhaust nozzle.

11. The apparatus of claim 10, in which the injector comprises a gas delivery tube having gas exit ports, and the tube is circumferentially located around the outer surface of the inner barrel.

12. The apparatus of claim 11, in which the tube is located proximate to and forward of the engine exhaust plane.

13. The apparatus of claim 10, in which the inner and outer barrels are each scallop-shaped in cooperative form to provide a shroud.

14. The apparatus of claim 1, in which the gas injected by the injector is engine bleed air.

15. The apparatus of claim 1, in which the gas injected by the injector is diverted engine core air.

16. The apparatus of claim 1, in which the gas injected by the injector is air obtained from a pressurized storage container.

17. The apparatus of claim 1, in which at least one synthetic jet actuator is used to inject gas into the area proximate to one or more engine nozzle portions.

18. The apparatus of claim 17, in which at least one synthetic jet actuator is used to inject gas into the area proximate to the core air flow of the engine.

19. The apparatus of claim 17, in which at least one synthetic jet actuator is used to inject gas into the area proximate to the fan air flow of the engine.

20. The apparatus of claim 17, in which at least one synthetic jet actuator is used to inject gas into the area proximate to the fan air flow of the engine, and at least one synthetic jet actuator is used to inject gas into the area proximate to the core air flow of the engine.

21. A method for reducing noise generated by an aircraft gas turbine engine, the method comprising:

(a) providing an apparatus for reducing noise generated by a gas turbine engine, the apparatus comprising at least one gas injector for injecting gas into the area proximate to one or more engine nozzle portions; and

(b) introducing gas into the apparatus during a takeoff portion of aircraft flight.

22. The method of claim 21, in which the introduction of air into the apparatus is halted during a cruise portion of the aircraft flight.

23. A system for reducing noise generated by an aircraft gas turbine engine, the system comprising:

(a) a source of gas;

(b) an apparatus for reducing noise generated by a gas turbine engine, the apparatus comprising at least one gas injector for injecting gas into the area proximate to one ore more engine nozzle portions.

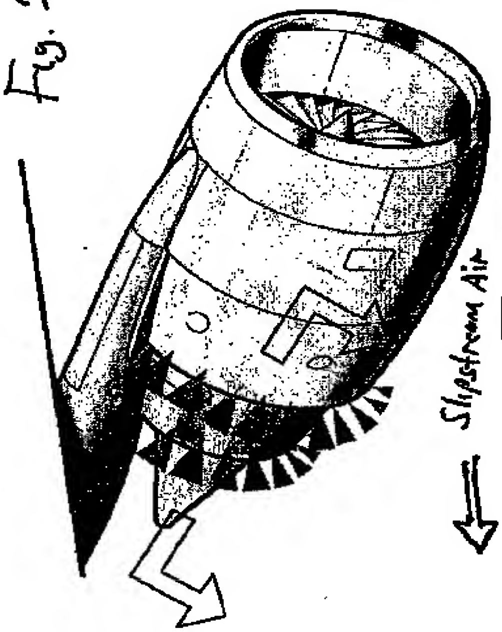


Fig. 1A

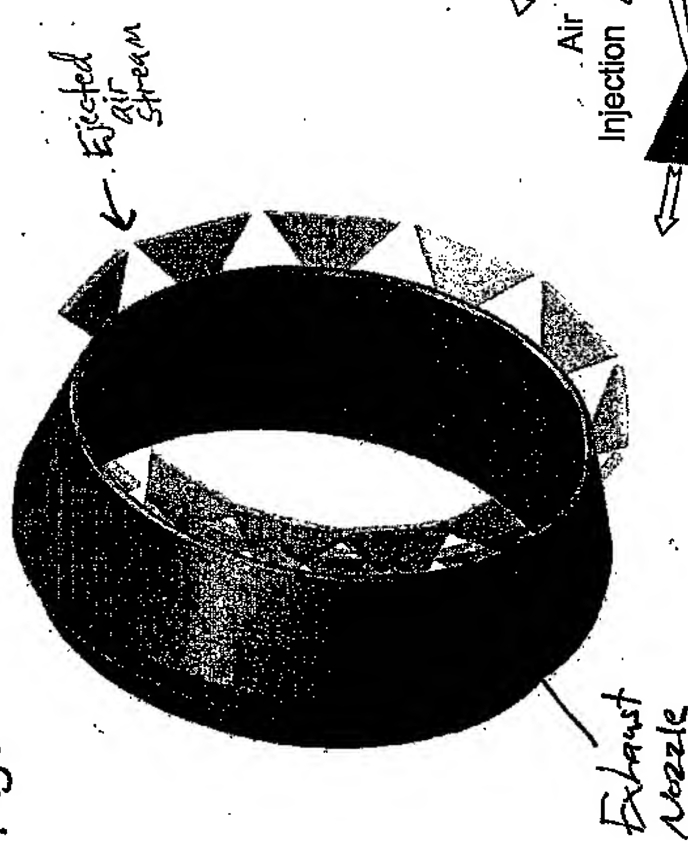


Fig. 1B

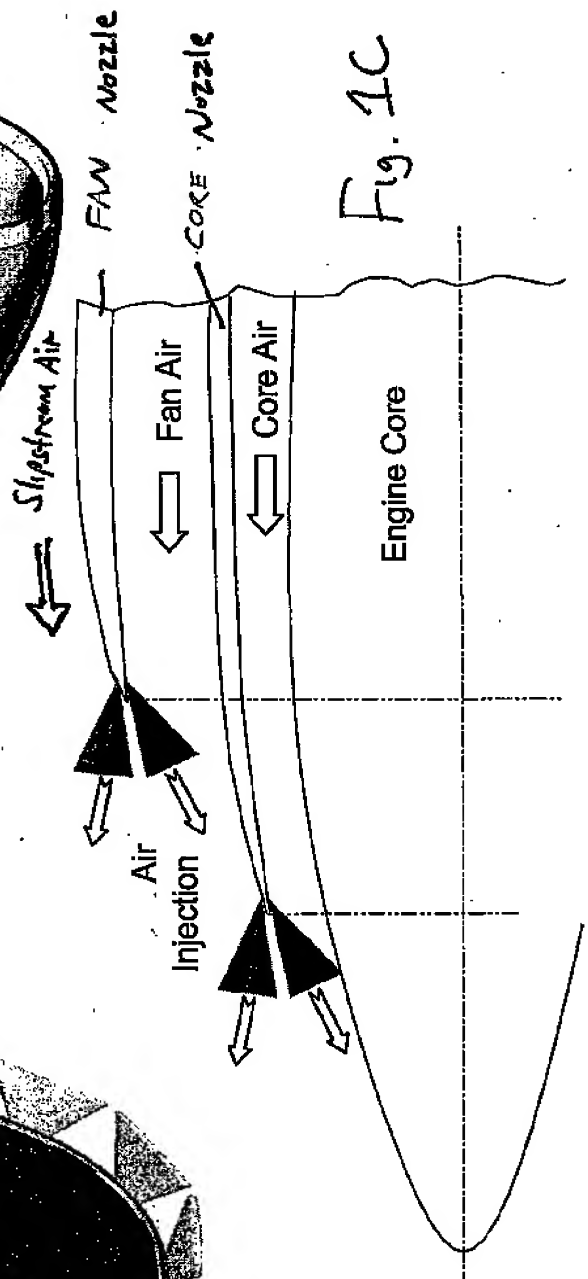


Fig. 1C

Fig. 1D

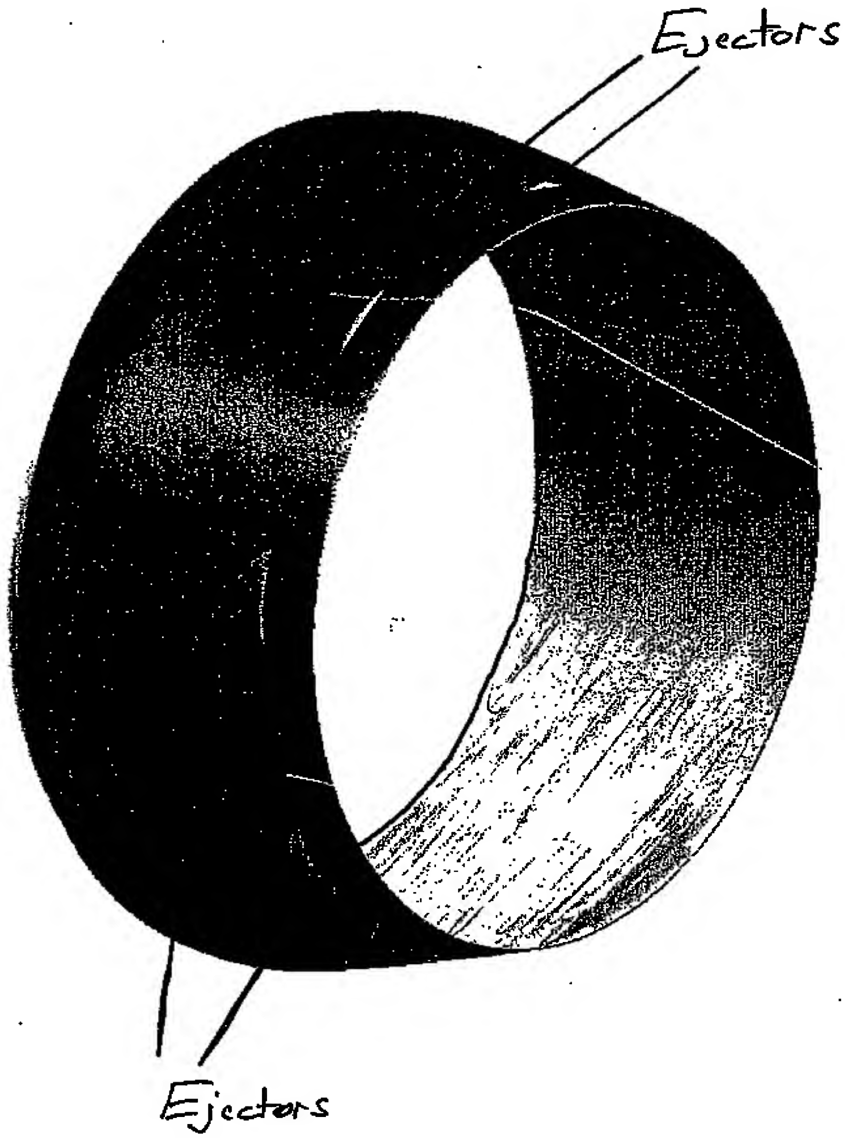


Fig. 1E

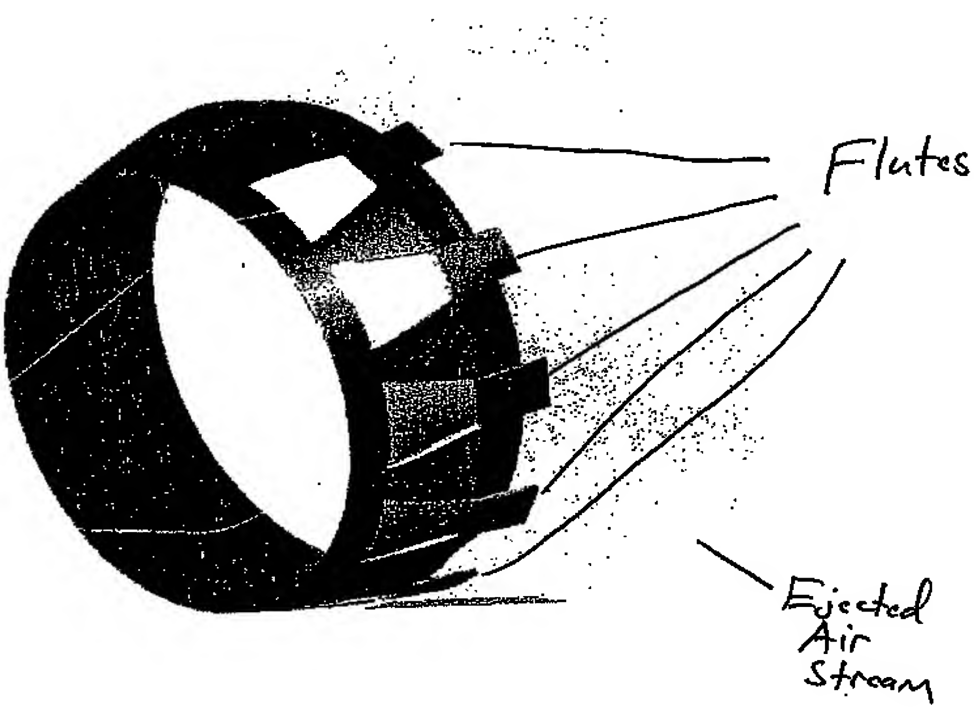


Figure 1F

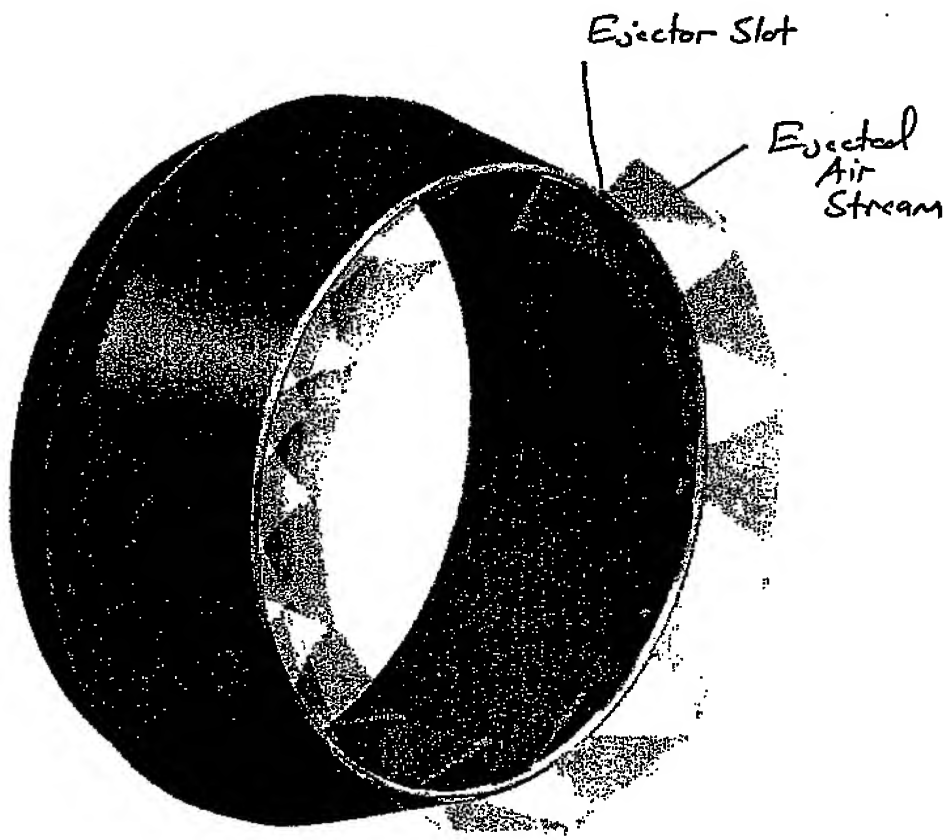


Figure 1G

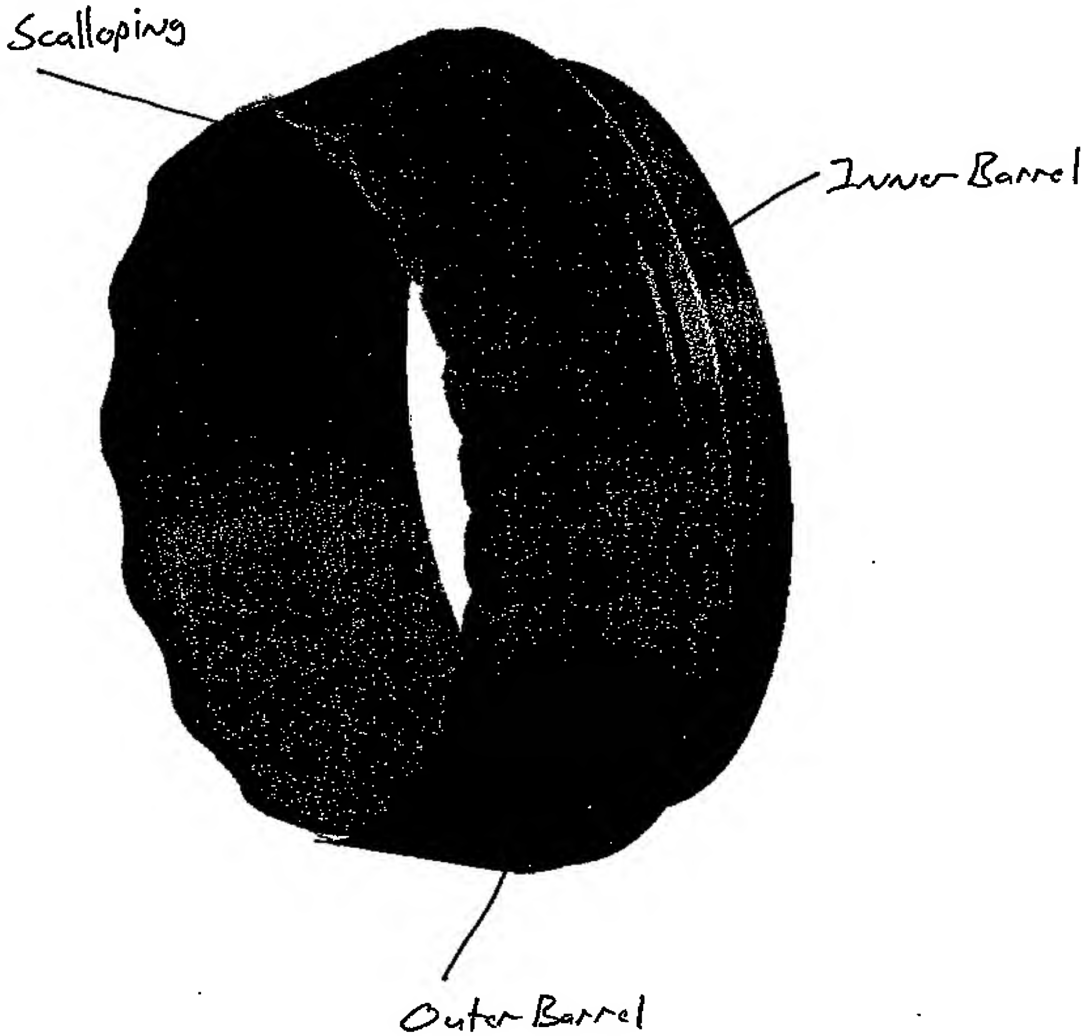
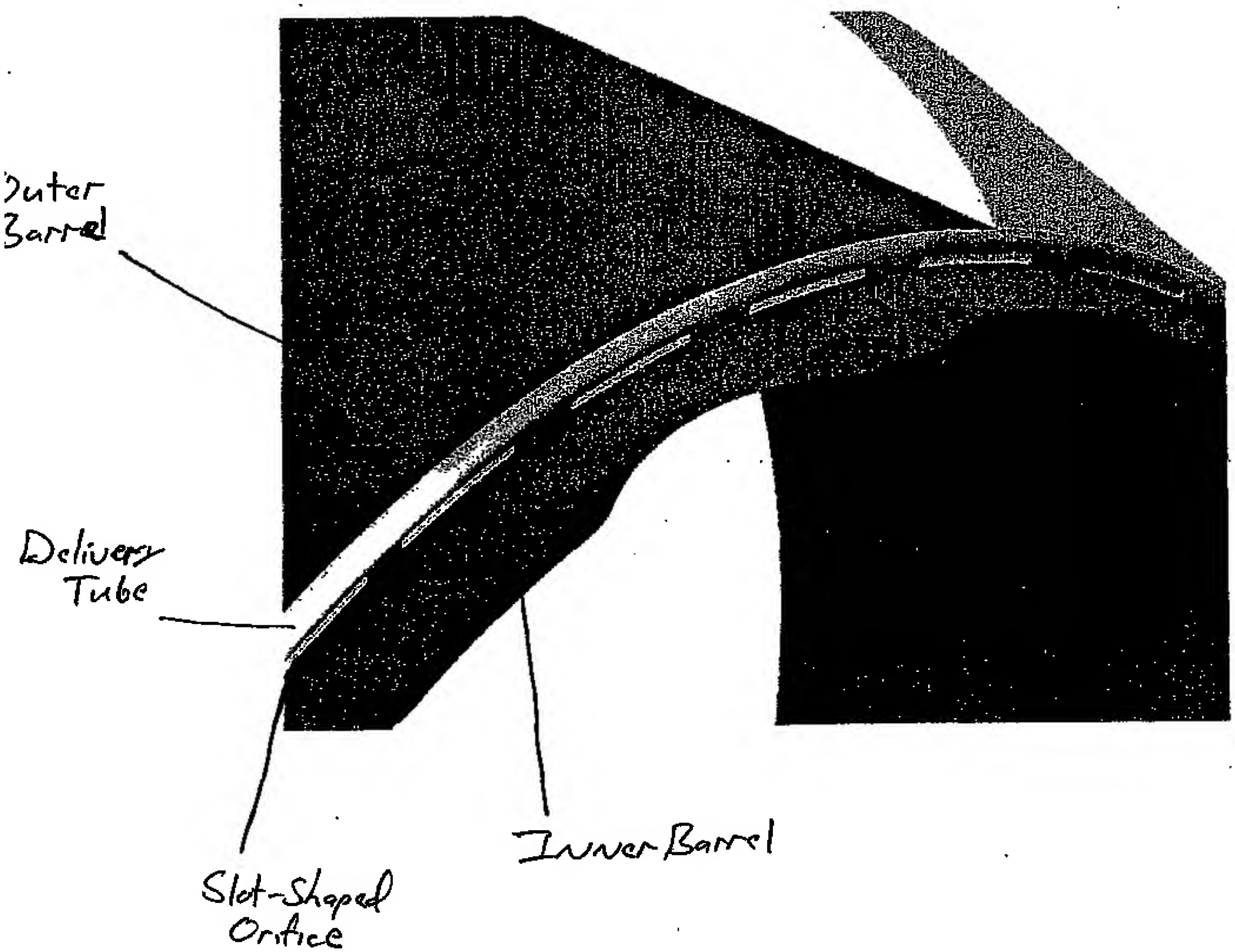


Figure 1H


Outer Barrel
Delivery Tube
Slot-Shaped Orifice
Inner Barrel

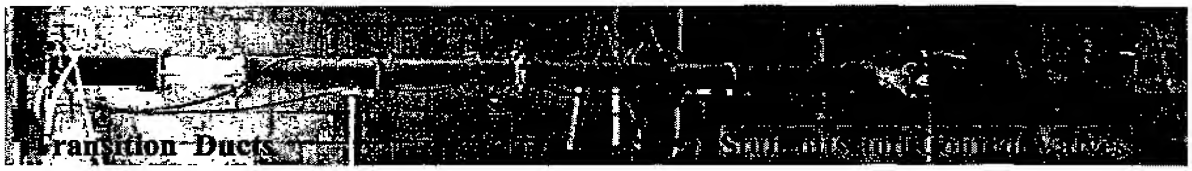


Figure 2. Overall Test Setup

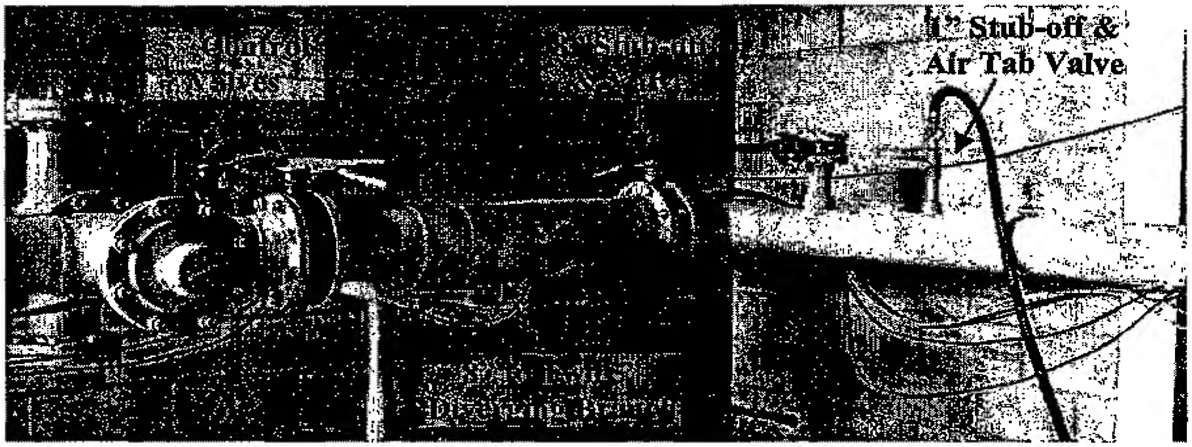


Figure 3. Control Valve Setup

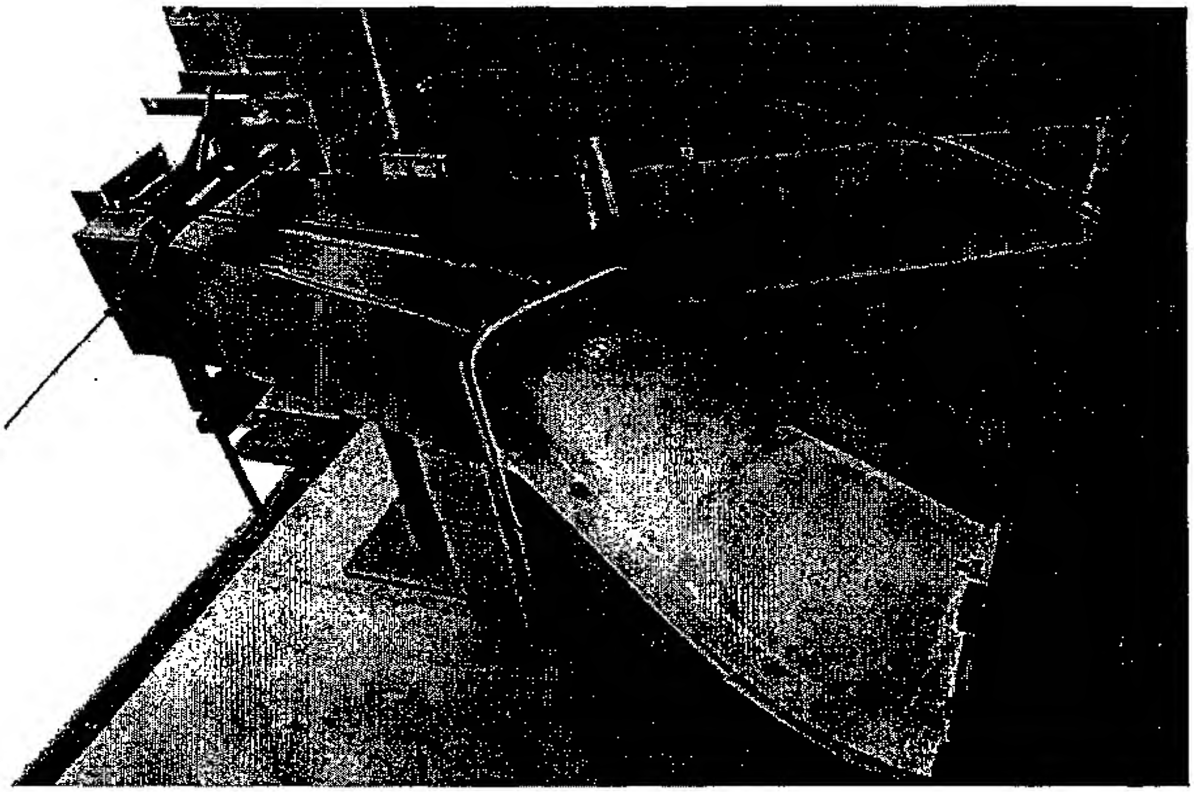
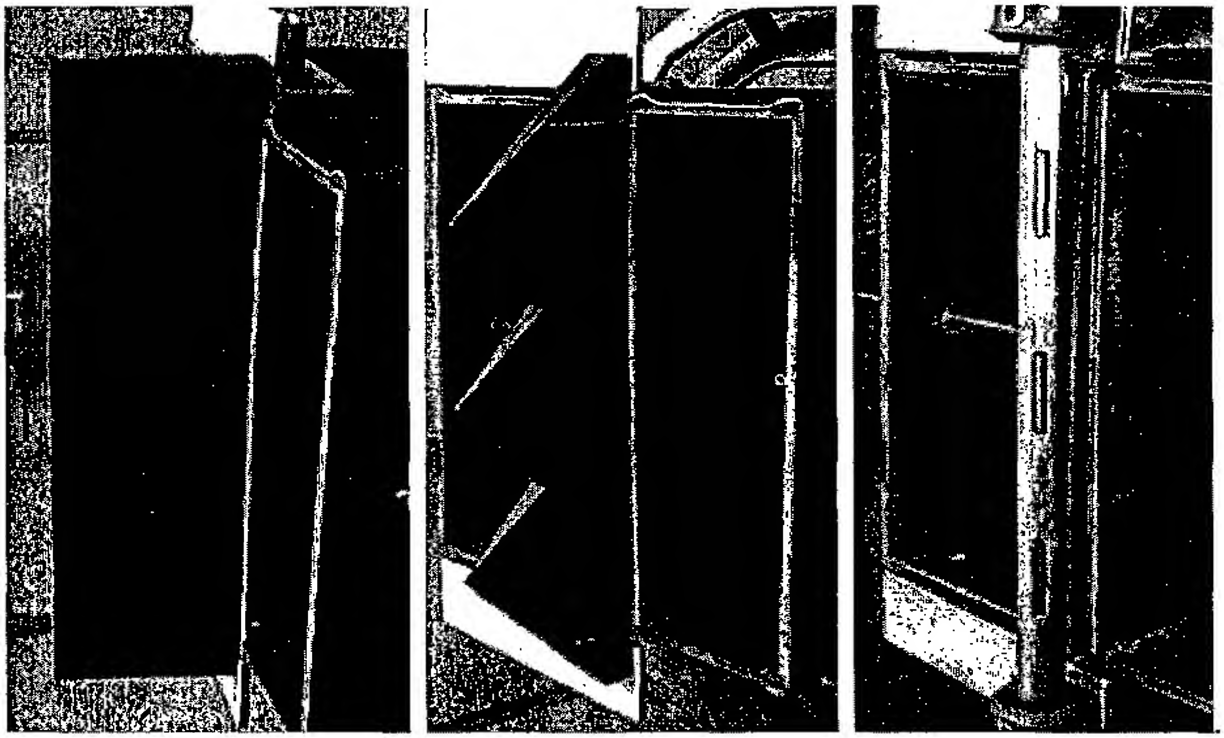


Figure 4. Transition Ducts



(a) *(b)* *(c)*

Figure 5. Mixer Configurations: a) Wedge, b) Sawtooth Tab, c) Air Injection

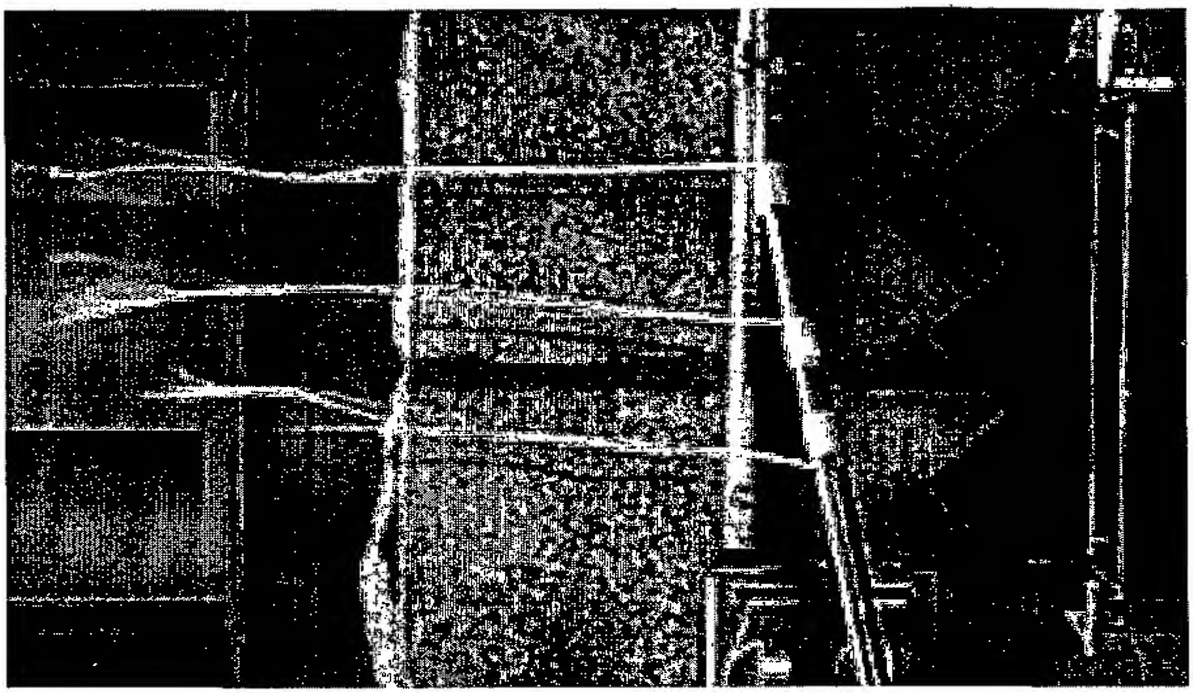
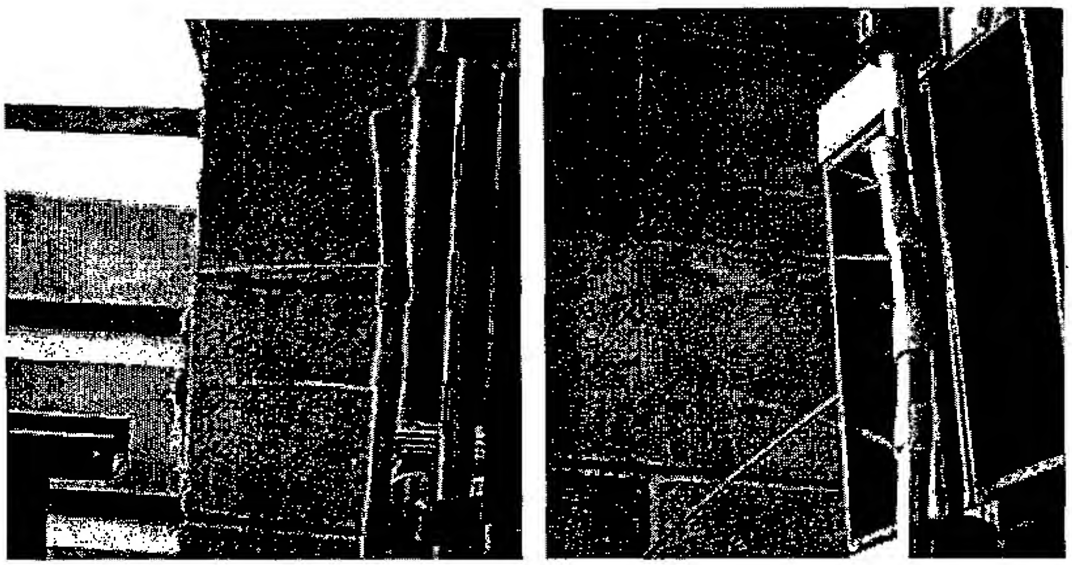
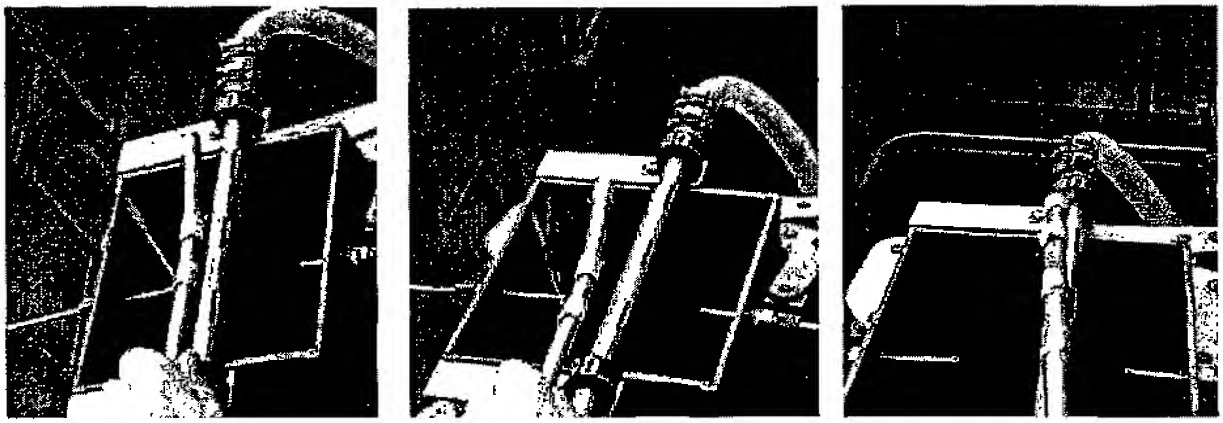


Figure 6. Flow Behind the Sawtooth Tab Mixer



(a) *(b)*

Figure 7. Flow Visualization From The Side Of The Air Injection Mixer: a) Air Injection Turned Off, b) Air Injection Turned On.



(a) *(b)* *(c)*

Figure 8. Flow Visualization From The End Of The Air Injection Mixer: a) Air Injection Turned Off, b) Air Injection Turned On (0.09 lb_m/s), c) Air Injection Turned On (0.16 lb_m/s).

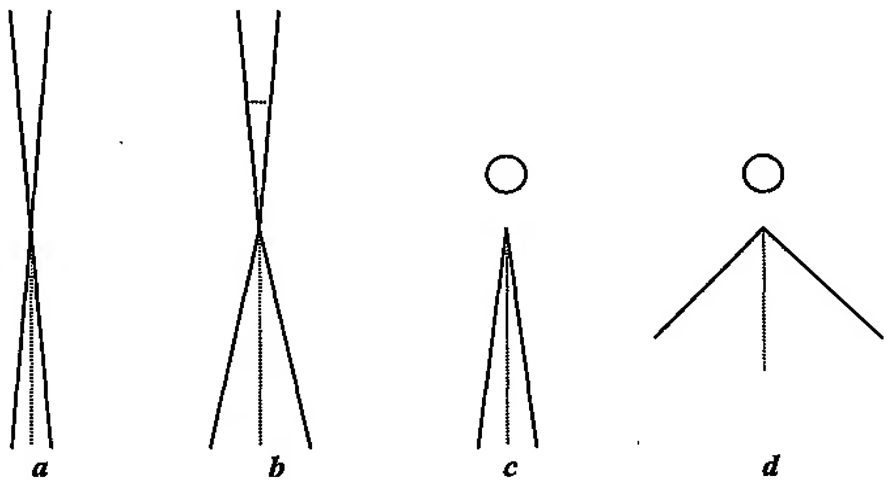


Figure 9. Representative Flow Patterns From Various Mixer Designs. a) Wedge Mixer, b) Sawtooth Tab Mixer, c) Air Injection Mixer With Air Off, d) Air Injection Mixer With Air On (0.16 lb_m/s).

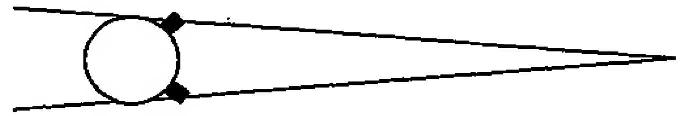


Figure 10. Possible Combination Injection/Wedge Mixer.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/30862

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : F02K 1/36
US CL : 60/262; 239/265.23

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 60/262, 226.1, 271, 39.02; 239/265.17, 265.23

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 3,527,317 A (MOTSINGER) 08 September 1970, see Figs. 2 and 7.	1-3, 5, 8-10, 16 and 23 ---- 17-22
X --- Y	US 5,947,412 A (BERMAN) 07 September 1999, see entire document.	1, 3, 4, 6-8, 14, 15 and 23 ----- 18 and 20-22
A, P	US 6,227,800 B1 (SPRING et al) 08 May 2001, see entire document.	1

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 22 JANUARY 2002	Date of mailing of the international search report 21 FEB 2002
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer J. Hurley for CHARLES G. FREAY Telephone No. (703) 308-0639